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14. ABSTRACT
This AFIOH ergonomic evaluation was requested as one aspect of an overall operational and environmental health assessment of handheld laser technology application in de-painting processes by the Air Force Research Laboratory (AFRL). The purpose of this evaluation was to identify possible ergonomic hazards and potential ergonomic improvements to the systems being researched by AFRL and to collect background data to support the development of design and/or performance standards for potential future equipment purchases. Components requiring de-painting may be removed from the aircraft for cleaning; however, small areas on the aircraft may be de-painted directly. The portable laser may be used to supplement automated/robotic de-painting during an overhaul of an entire aircraft or during a repair to a portion of the aircraft. Handheld laser use is anticipated to be no more than 2-4 hours a day, regardless of operating environment. Work-station configuration, vibration, trigger compression, angle of use, repetitive motions, awkward position fatigue considerations, and lower back risks were assessed. Repetitive wrist motions were a concern for long-term use. Training is required for proper use technique to prevent related musculoskeletal disorders. Vibration of the hand tool may need to be reconsidered if there are increases in the velocities of the current vacuum systems. The general recommendation would be to employ it in controlled base settings for further evaluation before full implementation into the field.

15. SUBJECT TERMS
AFIOH, ergonomic, vibration, repetitive, trigger, handheld laser, awkward position, fatigue, lower back, workstation

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DEPARTMENT OF THE AIR FORCE
AIR FORCE INSTITUTE FOR OPERATIONAL HEALTH (AFMC)
BROOKS CITY-BASE TEXAS

11 March 2004

MEMORANDUM FOR HQ AFMC/SGBE
4225 Logistics Ave., N209
Wright Patterson AFB, OH 45433

FROM: AFIOH/RSH
2513 Kennedy Circle
Brooks City-Base, TX 78235-5116

SUBJECT: Consultative Letter IOH-RS-BR-CL-2004-0030,
Ergonomic Assessment of Handheld Laser Technology in De-painting Process

1. INTRODUCTION

a. *Purpose*:

(1) At the request of Maj Carolyn Macola of HQ AFMC/SGBE, the Health and Safety Division of the Air Force Institute for Operational Health (AFIOH/RSH) conducted a qualitative ergonomic survey to evaluate and describe the process used to remove paint from metal surfaces with a handheld, class IV, laser technology being assessed by the Air Force Research Laboratory at Wright Patterson AFB (WPAFB) for potential implementation at depots. This AFIOH ergonomic evaluation was requested as one aspect of an overall operational and environmental health assessment of handheld laser technology application in de-painting processes by AFRL; and is coordinated by personnel at Air Force Research Laboratory (AFRL), Gerard Mongelli and Stefan Susta.

(2) The purpose of this study was to identify possible ergonomic hazards and potential ergonomic improvements to the systems being researched by AFRL, and to collect background data to support the development of design and/or performance standards for potential future equipment purchases.

(3) Personnel from AFRL and AFIOH/RSH convened on 3 Feb 04 at AFRL, WPAFB Base to observe the current laboratory testing procedures on the handheld laser technology. Randy Straw reported that laser technology has been used in automated de-paint processes, and building exterior cleaning (removing soot) in Europe. The handheld laser tools they are assessing are manufactured in Europe. The direct health risks from the laser technology are to the eyes and the skin. Indirect health risks pertain to the interaction between the laser and the substances being cleaned that could result in an inhalation, absorption or ingestion hazard of particulates or fumes. Other hazards pertain to ergonomics, noise, electrical, compressed and

toxic gases, radio frequencies, UV and visible radiation, ionizing radiation, and hazardous waste.

b. *AFIOH Personnel*:

Linda Schemm, Maj, USAF, BSC, Physical Therapist, MS-Occupational Ergonomics

c. *Personnel Contacted*:

Carolyn Macola, Maj, USAF, HQ AFMC
Stefan Susta, Contr, SAIC
Gerard Mongelli, Contr, HQ AFMC
Randy Straw, Contr, AFRL/MLSC
Pete Hall, AFRL, Technician/Operator

d. *Background*:

(1) This project was developed to migrate laser technology from AFRL research to demonstration and validation. Current depot de-painting process requires the use of chemicals such as methelyne chloride as normal maintenance practice to remove aircraft and support equipment coating systems. The focus of the AFRL project is to determine if a low powered hand-held laser system can be used to supplement automated de-painting of aircraft and components at the depot and field levels while eliminating chemical hazards associated with methelyne chloride use without creating other hazards.

(2) The proposed operating environments have not been fully defined. The portable laser may be used in an established depot and also in a deployed environment. Components requiring de-painting may be removed from the aircraft for cleaning; however, small areas on the aircraft may be de-painted directly. The portable laser may be used to supplement automated/robotic de-painting during an overhaul of an entire aircraft or during a repair to a portion of the aircraft. Randy Straw estimated that the handheld laser would be used no more than 2-4 hours a day, regardless of operating environment, but no data to this effect was available. AFRL personnel report that the operators of this device will be required to complete a specific training program and receive certification prior to using this technology.

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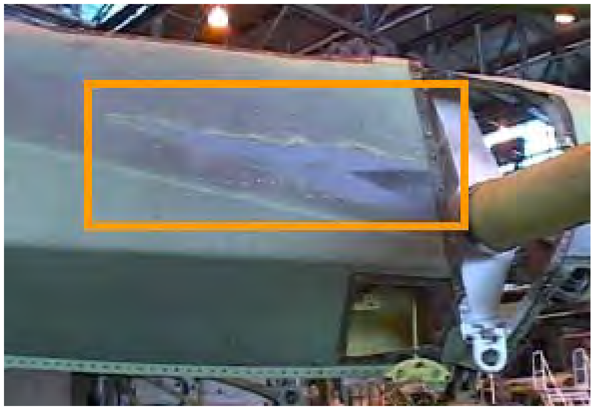

Figure 1: Potential Use- directly on aircraft

Figure 2: Potential Use- directly on aircraft

(3) The laboratory operator conducts tests on steel panels coated with various substances that may be encountered in the field. The greatest concern expressed by AFRL regarding ergonomic hazards are related to the hand tool properties, the human-tool interface and the biomechanical process used to remove paint from metal surfaces with the handheld class IV laser. The system is being evaluated in the artificial environment of a laboratory in hopes of predicting and preventing concerns in the field. This was not an assessment of the laboratory work environment.

2. SURVEY PROCEDURES:

a. *Information Review*

(1) AFIOH investigator reviewed information from AFRL regarding the laser technology: 1) Standard Operating Procedure applied during trials at Hill AFB of the Class IV laser operating of Cleanlaser 120 wt handheld laser, 2) Operating Instructions- Laser Cleaning System CL80 Q/120 Q Basic System (Cleanlaser), 3) Operating Instructions- Manually Guidable Machining Optical Machining System OS H 50L with Exchangeable Nozzles (Cleanlaser), 4) Quantel's Laserblast 1000 Instruction Manual (40 wt), 5) Air and Noise Sampling Report by Pacific Environmental Services, 6) Safety Plan (Draft) – Portable Laser

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Coating Removal by SAIC, 7) Laser Hazard Evaluation. Because this is a pre-deployment assessment, there are no injury/illness records pertaining to this process. The investigator interviewed the AFRL members involved in the project and the technician operating the devices. Personnel from AFRL and AFIOH/RSH convened on 3 Feb 04 at AFRL, WPAFB to observe the current laboratory testing procedures on the handheld laser technology.

(2) The operator reported that in the laboratory environment he uses the handheld lasers approximately 50% of his day (4 hours), with a work/rest cycle during the actual tool use of 30 minutes/10 minutes respectively. The operator is left hand dominant and reported no difficulty with using either tool in his left hand. He did note some discomfort in the left hand/forearm with the 40 watt laser. He reported some discomfort in his right hand, which he attributed to a recent increase in computer keyboarding. He had no other complaints of discomfort. The work surface he uses is at his waist level and angled at 45 degrees, and he stands on a cushioned rubber mat. He visually monitors the surface to assess quality of substance removal. He also noted that the 40 watt laser produces an audible sound, which he corresponds to visual confirmation of substance removal. The device needs to be held at a distance of 80-85 mm from surface. The 120 watt device has two hoses on the posterior side; the upper hose is for ventilation (cooling and capturing fumes and/or particles) and the lower hose is the fiber optic line (Figure 3). The 40 watt device has the fiber optic line entering the device at the bottom of the handle (Figure 10). The operator has added a ventilation hood to the firing end of the 40 watt device, with a ventilation hose attached to the bottom of it (Figure10).

b. *Workstation Configuration*:

(1) This evaluation is not specific to this workstation. The potential operating environments have not been fully defined. However, the work surface the laboratory operator uses is at his waist level and angled at 45 degrees, and he stands on a cushioned rubber mat. The pistol shape of each tool used at this workstation promotes awkward postures at the wrist (ulnar deviation) by tilting the front of the unit to meet the surface. It also creates awkward postures at the shoulder/neck and the trunk due to cradling lines and viewing the removal process at the laser-panel interface (Figure 4).

Figure 3: Laboratory use of 120watt hand held laser

c. *Specific Tool or System*.

(1) AFRL is conducting research on two particular systems, the Cleanlaser 120 watt system and the Quantel 40 watt system.

(2) General operation of either device reveals no significant vibration or reaction forces as reported by the operator and noted also by the evaluator during a trial use. The operation of either device also requires visual attention to substance removal, the 40 watt system more so than the 120 watt system. Both systems require appropriate vision protection (goggles/glasses). Both systems require the operator to protect the skin with clothing or sunscreen. The 40 watt system requires hearing protection.

(3) The 120 watt "Cleanlaser" handheld system is a pistol shaped unit equipped with a scanning laser that essentially fires multiple beams sequentially in a horizontal pattern. This allows for the laser to be moved in a vertical pattern manually, while cleaning an area approximately 2.5" in width. This width is adjustable through nozzle selection. This laser is equipped with interchangeable nozzles. A nozzle may have wheels attached to allow the operator to rest the wheels on the surface to be cleaned and move the handheld unit in a vertical direction (up/down) with a uniform distance of 80 mm between the laser and the surface. This allows for a uniform cleaning with less visual assessment required; however, the up/down motion is repetitive and may elevate the shoulder beyond 90 degrees of flexion. This handheld model also has a roller-free nozzle that allows for cleaning without contacting the surface directly. This may be useful when cleaning areas in a sharp angle such as seams, but would require greater skill and attention to maintain 80-85 mm distance. The handheld unit, with a nozzle and the ventilation hose and fiber optic line weighs 3 pounds, per the scale available at the laboratory. The handle length is 4" from the body of the unit. The diameter of the handle is 5 ½" (just under the activation button) and flares at the bottom.

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(4) The 120 watt model is equipped with the fiber optic line and ventilation line on the posterior side of the handheld unit. It has a ventilation and particulate/fume capturing duct at the anterior of the unit. The unit feels balanced with the weight centered over the handle area, in line with the fist, when the lines are not attached. However, when the lines are attached, the weight shifts to the tail end. This requires the operator to manually tilt the unit in an anterior direction. This creates awkward postures at the shoulder, neck and trunk. In order to do this with the least hand effort, the operator balances the hose lines over his shoulder and employs the opposite hand to guide the tool. This requires the operator to keep his shoulder slightly elevated and abducted (similar to cradling a phone). This awkward posture can cause unnecessary stress at the shoulder (acromioclavicular joint and the glenohumeral joint) and may contribute to bursitis or tendonitis in that region.

(5) Starting the laser is a three-step process. First, the operator turns on the main body of the machine. Second, he/she makes any necessary adjustments based on criteria for the substance being cleaned. Third, the hand held unit becomes active when the operator depresses the one button trigger on the handheld unit while pressing the "start" (green) button with the opposite hand on the handheld unit. For a left hand user, this means reaching across the body and unit to press the green button. A right hand user would reach across the body, but would not have to reach over the unit. The trigger is easy to actuate, but it is so small that it would be easy to slide off it unintentionally. There is no "emergency stop" button on the handheld; however, when the trigger is released, the laser stops. The handheld unit does not require nitrogen, so the lens of the unit requires cleaning every 6 months. There is no holster or hanger on the main unit, for securing the handheld unit when not in use.

Figure 4: 120watt device- vertical movement
(up/down, forward/backward)

Figure 5: 120watt device- posterior side. Green button is pressed to initially start handheld unit. Top portal is for ventilation hose, bottom line is fiber-optic.


Figure 6: 120watt wheeled nozzle, unable to view small upper capture vent from this angle.

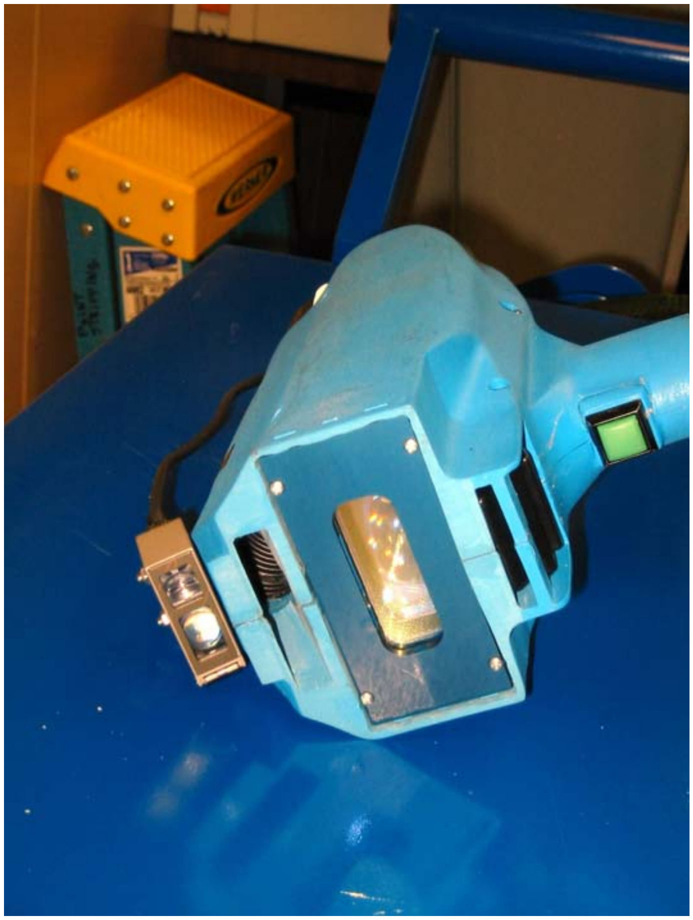

Figure 7: 120 watt- anterior end, without nozzle. Note upper capture vent.

Figure 8: 120 watt: note- no hanger or holster for handheld unit

(6) The Quantel 40 watt laser system is equipped with a focused single beam and requires compressed nitrogen gas, which keeps the lens clean. The operator must repetitively sweep the handheld unit laterally (side to side) in a 2-4” pattern, then move vertically and sweep laterally again, moving up the piece to be cleaned in small increments. This method requires the operator to be skilled at manipulating the unit to maintain a uniform distance of approximately 80 mm and to maintain a uniform cleaning depth. The operator reported that this model creates a high pitch sound that he correlates with visual assessments of cleaning at the appropriate depth. The operator wears hearing protection. This free-style method requires repetitive motions and a great deal of visual attention to the surface being cleaned. The 40 watt handheld unit is a pistol shape with a single digit trigger and a fixed nozzle. The nozzle seen in the photograph is a modification made by the operator as a capture vent for ventilation and a vacuum hose attaches to the bottom of the nozzle (Figure 9). The fiber optic line enters the handheld unit at the bottom of the handle. The handheld unit, with the capture vent and the ventilation hose and fiber optic line weighs 4.5 pounds, per the scale available at the laboratory.

(7) The handle is 1.5” in width, approximately 5” in diameter. The handle is a smooth aluminum, making it difficult to maintain a secure grip. There are also sharp edges against the palmar surface, combined with a large diameter handle and a single trigger, placing the hand at a biomechanical disadvantage to generate muscular force. The sweeping lateral motion necessary for the cleaning process can be achieved by repetitive wrist flexion and extension while exerting force to hold the unit upright. The grasping power of the hand is greatest when

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the wrist is in neutral position or slightly extended (Vern Putz-Anderson). The unit does have a suspension ½ ring on top, so it could be used with a suspension device. The method employed by the AFRL operator is to hold the ventilation hose like a handle for two-hand operation, which then requires bilateral wrist flexion and extension and minimal trunk rotation and also places his hand close to the laser exit, which is a safety concern (Figure 10). Or the operator can hold the arms/hands steady and rotate the trunk to achieve the sweeping motion. These three methods are force and repetition hazards, either to the wrists or to the low back.

(8) The operator in the AFRL laboratory uses this tool against a surface that is approximately 45 degrees from horizontal or vertical. This means the operator has to tilt the hand tool anteriorly to address the work surface, which places him in an awkward posture. In this case, he is left hand dominant so the left arm is abducted in order to point the laser at the surface to be cleaned. This awkward posture can cause unnecessary stress at the shoulder (acromioclavicular joint and the glenohumeral joint) and may contribute to bursitis or tendonitis in that region.

(9) The single trigger activates the unit and must be depressed through out use, with the laser turning off when the trigger is released. The trigger is compressed at the distal end of the finger due to the large diameter of the handle. Actuation of the trigger is easy but requires static muscle contraction to maintain the activation while supporting the weight of the unit and lines. The muscles subjected to static work require more than 12 times longer than the original contraction-duration for complete recovery from fatigue (Vern-Putz Anderson). The operator reported some discomfort in the muscles of the forearm and in the index fingers. This type of motion, posture and force could contribute to musculoskeletal disorder such as tendonitis or tenosynovitis (trigger finger).

(10) Starting the laser system is a three-step process. First, the main unit is activated at the unit control panel or at the remote (can be attached to operator's belt). Second, he/she makes any necessary adjustments based on criteria for the substance being cleaned. Third, the handheld unit is activated at the trigger. The trigger must remain depressed for operation, turning off the laser when the trigger is released. There is an emergency stop (red button) on the handheld unit that will shut down the main system when activated.

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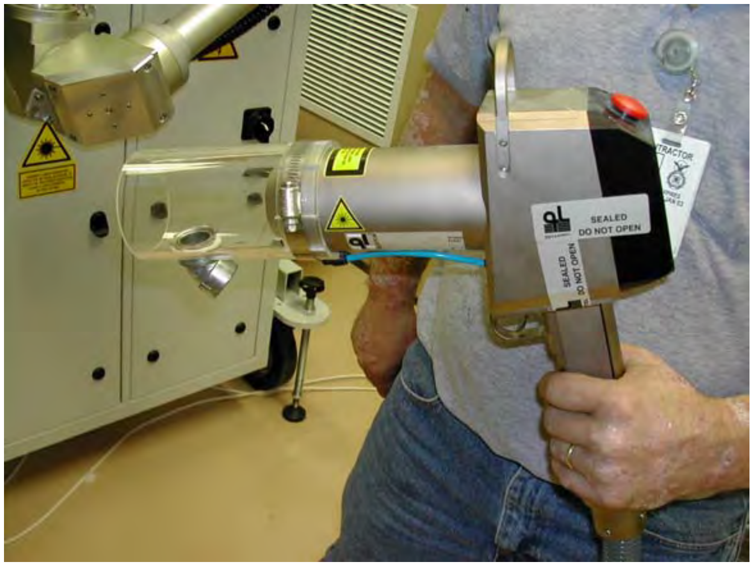

Figure 9: 40 watt- nozzle end was an addition of the operator as capture vent.
The ventilation hose is not attached.

Figure 10: 40 watt- operator’s preferred position for using this unit.

Figure 11: Quantel 40watt main system with the handheld unit resting on top. There is a remote to turn on the main system, then activate the handheld unit with the trigger. Note- no hanger or holster to secure the handheld unit.

3. RESULTS

a. *Tool/System*:

(1) The National Institute for Occupational Safety and Health (NIOSH) published a critical review of epidemiological evidence for work related musculoskeletal disorders in 1997, *"Musculoskeletal Disorders and Workplace Factors"*. NIOSH concluded that there is a substantial body of credible epidemiological research providing strong evidence of an association between musculoskeletal disorder and certain work-related physical factors. The risk of each exposure depends on a variety of factors such as the frequency, duration, and intensity of physical workplace exposures. In 1986, Rothman defined "causality in the relationship between workplace risk factors and musculoskeletal disorders as an event, condition, or characteristic that plays an essential role in producing an occurrence of the disease" (NIOSH). The goal for the ergonomist is to apply this evidence in a manner that prevents work-related musculoskeletal disorders.

(2) As noted earlier, awkward postures of the shoulder, repetitive motion with up/down motion of the shoulder while maintaining arm abduction were noted with the use of the 120 watt system pistol shaped handheld unit. Repetitive motion is required with the use of the 40 watt system as well. This motion may take place at the wrist (flexion/extension), the shoulder

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(internal/external rotation) or the low back (trunk rotation). Again, the arm activity is associated with awkward postures at the wrist (ulnar deviation to tilt tool), or at the shoulder (abduction to tilt tool). These factors present a potential risk for musculoskeletal disorders of the neck, shoulder and/or wrist/hand as noted by the research reviewed by NIOSH.

(3) There is evidence for a causal relationship between highly repetitive work and neck and neck/shoulder musculoskeletal disorders. Most of the epidemiological studies reviewed by NIOSH defined “repetitive work” for the neck as work activities that involved continuous arm or hand movements that affect the neck/shoulder musculature and generate loads on the neck/shoulder area. There is strong evidence that working groups with high levels of static contraction, prolonged static loads, or extreme working postures involving the neck/shoulder muscles are at increased risk for neck/shoulder musculoskeletal disorders. There is evidence for a positive association between highly repetitive work and shoulder musculoskeletal disorders involving combined exposure to repetition with awkward shoulder postures or static shoulder loads. NIOSH also noted evidence for a relationship between repeated or sustained shoulder postures with greater than 60 degrees of flexion or abduction and shoulder musculoskeletal disorders. The evidence for specific shoulder postures is strongest where there is combined exposure to several physical factors like holding a tool while working overhead.

(4) Carpal Tunnel Syndrome (CTS) is probably the first musculoskeletal disorder one thinks of when referring to the wrist or hand. Due to the repetitive motion at the wrist with the use of the 40 watt handheld unit, and the force required to support and manipulate the 4.5-pound unit, the operator may be at risk for carpal tunnel syndrome. There is evidence of a positive association between highly repetitive work alone or in combination with other factors and CTS. There is also evidence of a positive association between forceful work and CTS. There is insufficient evidence of an association between CTS and extreme postures; however, NIOSH noted laboratory-based studies of extreme postural factors supporting a positive association with CTS. There is evidence of a positive association between work involving hand/wrist vibration and CTS. The strongest evidence of a positive association is between exposure to a combination of risk factors (e.g., force and repetition, force and posture) and CTS. Based on the epidemiological studies reviewed by NIOSH, they concluded that exposure to a combination of the job factors studied (repetition, force, posture, etc.) increases the risk for CTS. These factors are present in the manner and position in which the handheld lasers were used in the laboratory. Epidemiological surveillance data, both nationally and internationally, have also consistently indicated that the highest rates of CTS occur in occupations and job tasks with intensive manual exertion such as meatpackers, poultry processors, and automobile assembly workers (NIOSH).

(5) Other hand musculoskeletal disorders can occur with high repetition, force and posture. These could include tendonitis or tenosynovitis at the thumb (DeQuervain’s disease) or at the index finger (Trigger Finger). Due to the sustained hold of the trigger with a wide diameter handle on either unit while supporting and manipulating the unit, the operator may be at risk for tendonitis. There is evidence of an association between any single factor (repetition, force, and posture) and hand/wrist tendonitis, based on currently available epidemiological data. There is strong evidence that job tasks that require a combination of risk factors (e.g., highly repetitious, forceful hand/wrist exertions) increase risk for hand/wrist tendonitis.

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(6) The low back may be at risk for musculoskeletal disorder in the de-painting process depending on the workstation configuration and/or method employed. NIOSH concluded there is strong evidence that low-back disorders are associated with work-related lifting and forceful movements and evidence that work-related awkward postures are associated with low-back disorders. Risk is likely related to speed or changes and degree of deviation from neutral position.

4. DISCUSSION

a. *General Guidelines*

(1) In developing the *Level I Ergonomics Methodology Guide for Maintenance and Inspection Work Areas* 1997, recommendations for hand tool criteria were included. This document can be obtained at https://www.afms.mil/ergo/ under the "publications" button. *The Occupational Ergonomics Handbook*, edited by Waldemar Karwowski and William Marras, was also referenced.

(2) The Occupational Safety and Health Administration (OSHA) standard that applies to hand tools, although it is not specific to lasers, is 29CFR 1926.300. This pertains to the following: maintenance of tools in a safe condition, tool guards, point of operation guarding, danger zone, personal protective equipment, on-off controls, and constant pressure switch.

(3) The following are general guidelines for the workstation-tool-worker interface. The main concept for protecting the worker from work-related musculoskeletal disorders is: "bend the tool not the worker".

(4) In general, the hands should be at elbow height while working. The work surface height may need to be adjusted for the worker, or the worker's location may need to be adjusted to meet the work surface height. Maximum speed for manual jobs occurs when arms are at one's side and elbows are bent to right angles.

(5) Work surfaces may need to be angled to match the tool, or the tool may need to be angled to match the workstation in order to keep the workers body in the most neutral postures possible. A vertical surface at elbow height to the worker matches well with pistol grip tools that allow the worker to use a power grip. If the vertical surface were at knuckle height, an in-line tool would be appropriate to allow the worker to use a power grip. If the vertical surface were at shoulder height, it would be better to raise the worker to meet the surface (scissor lift, platform ladder) so the worker can position to the work surface appropriately for the tool being used. A horizontal surface at elbow height to the worker would match well with an in-line tool. If the horizontal surface were at knuckle height, a pistol grip would be more appropriate.

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Poor design Better design

Poor design Better design

Figure 12: Work surface-tool-worker interface

(6) Major issues to be considered when developing or selecting a hand tool include: designing the tool for the task, flexibility to be useful in a variety of work situations, tool should encourage neutral and comfortable body postures, the tool should not require excessive forces, and the tool should not expose the user to hard edges, excessive vibration, impact, or torque. Essentially, the hand tool selection should consider how the particular task and workstation relate to the capabilities and limitations of the human operator.

(7) Power hand tools should be well balanced with all the attachments installed, with the hand tool center of gravity aligned with the center of the grasping hand so that the operator does not have to overcome moments by rotating the hand or wrist. Generally the hand tool and its attachments should not exceed 5 pounds, however experienced hand-tool operators have

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indicated a preference for tools that weigh approximately 2 to 4 pounds (Karwowski, Marras). Cables and hoses should be minimized as much as possible. Attachment of these lines should be located to keep the tool balanced and minimize interference and drag. Swivel attachments and flexible tubing may improve handling.

(8) The handle/grip diameter of 1.25-2.0" is a general rule, with span for including a trigger of 2.5-3.5", however, Petrofsky found that a maximum grip force is achieved at approximately 2.0-2.4" (5-6cm) (Karwowski, Marras). This can vary with hand size, with large handed operators having a maximum grip force at approximately 2.4" and small-handed operators having a maximum grip force at approximately 2.0". The handle should be smooth, compressible and provide a friction grip surface. Handles should not be bare metal because it reduces the friction between the hand and the surface, increasing the muscular force required to grasp the tool. Rubberized insulating surfaces are preferred. The handle length should be long enough to allow adequate contact between the hand and the handle, without digging into the palm, but not so long that it interferes with the motion at the wrist, elbow or shoulder. Generally this means a length of approximately 4", but a length of 5" may be preferable if gloves are to be worn, for power grip tools. The handle shape should not have any sharp edges or abrupt curves, avoiding channels for individual triggers. A tool that must be directed in a particular manner could have a subtle discontinuity (flat area) in the handle to indicate direction or a flare towards the bottom to decrease hand slipping downward. Full handgrip force required to use the tool should not exceed 8 pounds. The tool should be right or left hand user friendly to allow operator to use either hand, providing rest breaks for each hand.

(9) Triggers and buttons should be positioned to allow activation without causing isolated stress at fingers or thumbs. Extended length triggers distribute the force of squeezing the trigger and grasping the handle to several fingers to reduce the stress at the index finger. The trigger length recommendation is 1.5"-2.25". The recommended trigger width is 0.5-1.0" to allow the entire finger pad to contact the trigger. The depth should be approximately 0.12-0.37" to limit finger extension. The force required to activate the trigger should be minimal, less than 1 pound. The operator should be able to easily sense actuation and release of the trigger.

5. RECOMMENDATIONS

a. *Workstation Design*

(1) The workstation and operating environments have not been fully defined, yet tool recommendations are partially dependent upon how they will be implemented. Because the work environment may be variable, flexibility will be important for implementation of a handheld laser cleaning system.

(2) In a fixed location such as a depot, an overhead suspension system for supporting handheld tools during use could be considered. Permanent or portable scaffolding frames to allow workers to position themselves appropriate to the work area on the aircraft should also be considered. Because the area to be cleaned may be located in unusual places, stair ladders with appropriate railings, and/or power lift platforms with appropriate railing and safety features should be considered in order to align the worker with the work.

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(3) If the product to be cleaned is removed from the aircraft, support frames that can clamp the piece in place, and position it at a height and angle appropriate to the user and the tool would be appropriate. Providing proper mats for cushioning the lower extremities during prolonged standing is important. Sit/Stand stools that allow the worker to change position may be a consideration if they will be working in one area for prolonged periods of time.

(4) In a deployed environment, equipment would be similar, but may have to be more portable such as portable stair ladders, suspension frames (hoist), and A frames. The goal continues to be that of protecting the worker from injury and work related musculoskeletal disorders, while maintaining effective work strategies.

Figure 13: A simple A-Frame for mounting work

Figure 14: Height adjustable work surface-scissor lift

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Figure 15: Suspension Systems

Figure 16: Scaffolding

Figure 17: Platform rolling ladder Figure 18: Scissor lift work platform

b. *Tool/System Design*

(1) <u>120 watt Cleanlaser System</u>

Problems: Pistol shape
Solution: This shape is fine if it is employed at a vertical workstation that is waist level to worker or horizontal surface that is at knuckle height to worker. This is functional in the contact method (nozzle rests on surface) and free-style method (no tool-surface contact) of cleaning. This could entail removing parts from the aircraft and securing them in a frame at appropriate heights and angles for the individual worker or providing appropriate height adjustable platforms to position the worker appropriately to the surface being cleaned. If the work surface is the actual aircraft and has contours to contend with, the use of the pistol shape may lead to awkward postures. To allow flexibility for use in a variety of work situations, an articulating handle that can be fixed at various angles on an in-line or 90 degree tool could be adjusted to complement the angle or contour of the work surface (Figure 19). If the work surface is vertical, the tool can be positioned in a pistol shape. If the surface is contoured or more horizontal, the tool could be angled to allow the nozzle to rest on the work surface

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(provided it was equipped with wheels or guide) while the operator moved it forward/backward. Resting the nozzle would provide a counter balance point because the center of gravity of the tool could be too far forward for unsupported operation. A second attachable handle would help balance the tool and provide a second point of control for the operator. An articulating handle may not be technically possible, so a 90 degree two handle style could still be considered (Figure 20). This would be an option when the tool can rest on the work surface, or during free-style cleaning with the work surface angled appropriately to height to allow more neutral postures for the worker.

(2) **Problems**: Weight of pistol shaped tool is imbalanced with hoses attached. The hoses are difficult to manage due to posterior placement.
Solution: Tool redesign so attachment of lines maintains center of gravity in line with operators fist to balance pistol shaped tool. Weight balance needs to be considered if an alternative shaped tool is designed with ventilation and fiber-optic lines as well. Management of the hoses could be improved with relocating attachments at the bottom of the tool, or with flexible hosing or swivel attachments so that the hoses can hang under the operators arm rather than over the shoulder. Another option to consider would be a suspension system to support the hose lines. A permanent overhead suspension system may work well in a depot. Or an articulating arm could be added to the main body of the unit, to suspend the hoses from the handheld unit for the operator. This may work while the operator is on ground level and close to the unit, but if the worker is on a raised platform or working in tight spaces, the angle of pull could increase the torque at the operator's hand. A portable frame (hoist) could be employed in a deployed environment; but the same issue would apply and it could also present other hazards (tripping, head clearance). A tool belt with loops to support hoses close to the body but away from the feet could be helpful but relies on operator compliance. So the best option is likely redesign with the hoses attached towards the bottom of the tool, with the weight well balanced with flexible lines and swivel attachments.

(3) **Problem**: The handle diameter is large and the button trigger is small and may be slipped off easily.
Solution: The recommended button width is 0.5-1.0" to allow the entire finger pad to contact the trigger. The handle/grip diameter of 1.25-2.0" is a general rule, with span for including a trigger of 2.5-3.5". Petrofsky found that a maximum grip force is achieved at approximately 2.0-2.4" (5-6cm) (Karwowski, Marras).

(4) **Problem**: When the operator activates the handheld unit, he/she depresses the one button trigger on the handheld unit while pressing the "start" (green) button with the opposite hand on the handheld unit. For a left hand user, this means reaching across the body and unit to press the green button. A right hand user would reach across the body, but would not have to reach over the unit.
Solution: Relocate the green "start" button to a centerline position so reach is equal for right or left hand users.

(5) **Problem**: When the unit is not in use, the handheld unit is not secured.
Solution: Add a hook, holster or pocket on the main body of the system to store the handheld unit.

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(6) <u>40 watt Quantel System</u>

Problems: Pistol shape
Solution: This shape is fine if it is employed at a vertical workstation that is waist level to worker or horizontal surface that is at knuckle height to worker. This could entail removing parts from the aircraft and securing them in a frame at appropriate heights and angles for the individual worker or providing appropriate height adjustable platforms to position the worker appropriately to the surface being cleaned. If the work surface is the actual aircraft and has contours to contend with, the use of the pistol shape may lead to awkward postures. To allow flexibility for use in a variety of work situations, an articulating handle that can be fixed at various angles on an in-line or 90 degree tool could be adjusted to complement the angle or contour of the work surface (Figure 19). If the work surface is vertical, the tool can be positioned in a pistol shape. If the surface is contoured or more horizontal, the tool could be angled to allow the nozzle to rest on the work surface (provided it was equipped with wheels or guide) while the operator moved it forward/backward. Resting the nozzle would provide a counter balance point because the center of gravity of the tool could be too far forward for unsupported operation. A second attachable handle would help balance the tool and provide a second point of control for the operator. An articulating handle may not be technically possible, so a 90 degree two handle style could still be considered (Figure 20). This could be an option when the tool can rest on the work surface or during free-style cleaning provided the work surface is angled appropriately to height.

(7) **Problems**: The weight of the tool is 4.5 pounds with the hoses attached. Although this is less than 5 pounds, experienced hand-tool operators have indicated a preference for tools that weigh approximately 2 to 4 pounds. Also, the smooth aluminum material increases the grip forces necessary to support the tool.
Solutions: Reduce the weight of the tool and improve the friction coefficient through design and material selection. A plastic material may achieve both. A second handle could be considered so the tool can be supported with 2 hands, therefore distributing the weight. Another option is to use a suspension device. A permanent overhead suspension system may work well in a depot. Or an articulating arm could be added to the main body of the unit, to suspend the hoses from the handheld unit for the operator when he/she is in close proximity to the main unit. A portable frame (hoist) could be employed in a deployed environment; however, this could cause other hazards (tripping, head clearance). Either may not be employable when the operator must work from an elevated platform or in tight spaces. So, the better option would still be tool redesign.

(8) **Problems**: The smooth aluminum surface, sharp edges at the palmar surface of the hand, large diameter handle and single trigger.
Solutions: Improve the friction coefficient through design and material selection. A plastic material or a rubberized handle would address this. Reduce the handle size and remove sharp edges. The handle/grip diameter of 1.25-2.0” is a general rule, with span for including a trigger of 2.5-3.5” to allow activation without causing isolated stress at fingers or thumbs. Petrofsky found that a maximum grip force is achieved at approximately 2.0-2.4” (5-6cm) (Karwowski, Marras). The trigger length recommendation is 1.5”-2.25” to distribute the force of squeezing the trigger and grasping the handle to several fingers. The recommended trigger width is 0.5-1.0” to allow the entire finger pad to contact the trigger.

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(9) **Problems**: This handheld system requires repetitive sweeping motions side/side or up/down.
Solutions: System redesign with sequential firing laser beams to reduce the repetitive sweeping motions. Another option would be to mechanize the handheld so that the head of the unit rotates to sweep the beam; however, this could lead to adding further weight and increasing grip forces to support the moving parts. So, beam redesign would appear to be the best option, if this is within the manufacturer's ability.

(10) **Problems**: Requires significant skill to maintain 80-85 mm distance between cleaning surface and laser exit.
Solution: Consider a guide attachment to the front end of the nozzle to be used when cleaning uniform surfaces. The freestyle method may still be the best option for unusual surfaces like seams and sharp angles.

(11) **Problems**: No built in ventilation/vacuum system for collection of fumes and particulate. The operator modified ventilation system also acts as a handle, placing his hand very close to the laser exit.
Solution: Tool redesign to incorporate a vacuum system without increasing tool weight with consideration for hose placement, weight balance and ease of managing hose lines: flexible hoses, swivel attachments, hose location.

Figure 19: Example of articulating tool, screwdriver

Figure 20: Example of 90 degree tool, buffer

Figure 21: Example of pistol grip tool, with 2-finger trigger,
appropriate diameter and length, smooth surface.

c. *Work Organization*

(1) The operating environment has not been well defined at this time. It has been estimated that the handheld laser units would not be used in excess of 2-4 hours per day. The task is somewhat visually demanding, in that the operator is visually assessing substance removal throughout the cleaning process with the handheld unit, but the operator is not making precise determinations. The laboratory operator has employed a work/rest cycle of 30 min work/10 min rest with the tool use. The operator changes tasks through out the workday, so he estimates that 50% of his day is spent operating the handheld units.

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(2) Jobs where long-duration physically or perceptually demanding tasks are done without breaks (unloading a conveyor) usually have a high work/rest cycle. Jobs with many tasks in a variety of effort levels (cafeteria attendant) can be patterned to have low work/rest ratios by alternating between tasks of different effort levels (Kodak Co). A rest phase may not have to be a cessation of all activity, but a period of doing light activity.

(3) When implementing the handheld laser technology into the work environment, the job demand considerations should include a work/rest cycle by providing multiple tasks at variable levels of effort that can be performed at various times during the workday, allowing worker self-paced operations as feasible. Stretching breaks should be included in the workday. The AFRL laboratory operator has managed well with a 30min/10min work rest cycle, while limiting overall tool use to 4 hours per day. Job rotation may be another strategy employed by training more than one technician on the handheld laser technology.

d. *Other Health/Safety Concerns*

(1) Body Mechanics Instruction should be provided to the operators during initial training and annually thereafter. Proper work technique is important to preventing musculoskeletal disorders. Video training tools are available, but it is also advisable to have the unit safety officer include base level Public Health or Rehabilitative Services in a training plan for body mechanics specific to the work environment and this tool's application.

(2) Vibration of the hand tool may need to be reconsidered if there are increases in the velocities of the current vacuum systems. During trial use, the investigator noted no significant vibration. However, AFRL is conducting air-sampling studies that may indicate a need to increase vacuum system velocity. If this were to be necessary, vibration at the hand tool would need to be considered when determining methods for controlling inhalation hazards.

6. CONCLUSION

a. *Summary*

(1) This report does not imply AFIOH endorsement of this particular method of de-painting nor the tools assessed in this process. Appropriate application is to be determined through a thorough Occupational Health Risk Assessment regarding laser use in regards to the DoDI 605.11 Protection of DoD Personnel from Exposure to Radiofrequency Radiation and the AFOSH 48-139 Laser Radiation Protection Program by AFRL. This ergonomic evaluation is just one aspect of that assessment. Provided this method were determined to be an appropriate de-painting method and the item manager approves its use, the general recommendation would be to employ it in controlled settings, such as the depots, before considering deployment to the field.

(2) The primary recommendation for both tools under consideration would be tool re-design. An articulating handle would provide a great deal of flexibility in application for cleaning/de-painting aircraft and parts. However, a design engineer may determine an articulating handle on a handheld laser is not technically feasible due to ventilation and laser requirements. In which case, the pistol shape may be the best option. In either instant, the tool should be redesigned to address weight, balance, diameter, trigger, sharp edges, and hose

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attachment issues. Attention to the work environment will need to be emphasized so that the work can be positioned appropriately to the worker, or the worker can be positioned to the work for use of the tool in the most neutral postures possible to prevent musculoskeletal disorders.

(3) It would also be beneficial for the manufacturer of the 40 watt system to consider methods for reducing the repetitive wrist motions, such as a synchronized laser firing system.

(4) Training for proper body mechanics in the work environment cannot be over emphasized. Proper technique can be a key factor in preventing work related musculoskeletal disorders.

(5) It would be beneficial to include bioenvironmental engineering in the planning and fielding of this technology at their depots. They could assist in potential hazard identification and prevention, and establishment of training and standards of operations specific to their worksite. Further ergonomic consultation may be appropriate when this new technology is fielded.

(6) We greatly appreciate the cooperation of the AFRL staff during this assessment. If you have any questions concerning this report, please contact me at DSN 240-6116.

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Attachments:
1. Tool Worksheet
2. Video Resources
3. References

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Hand Tool Evaluation Worksheet

Table A.3
Hand Tool/Power Tool Evaluation Worksheet

Date:	**Evaluator:**
Job:	**Type:**
Manufacturer:	**Model Number:**
Model Name:	**Price:**

Category	Parameter	Measure	Meets Criteria Yes	No	N/A
General	Handiness	Tool should be easily used with either the left or right hand.			
	Repetition	Tool should minimize repetitive movements.			
	Ease of Use	Tool should be easy to use.			
	Ease of Maintenance	Tool should be easy to maintain.			
Grip Angle	Wrist and Arm Posture	Handle angle and location should allow a straight wrist and neutral arm position while the tool is being used.			
	Back and Neck Posture	Handle angle and location should allow the user to see the work without having to tilt or bend the head or back.			
Force Requirements	Activation Forces	**Full hand** grip forces required to use tool should be less than 8 lb. (3.6 kg.)			
		Fingertip grip force required to use tool should be less than 2 lb.(0.91 kg.)			
	Two hand activation	Tool should allow two hands when applied forces are high or when additional control is needed.			
	Tool Weight	Tool (and associated cables/hoses) should weigh less than 5 lb. (2.3 kg.) or be mechanically supported.			
	Tool Balance	Tool's center of gravity should be close to or at the grip location.			
	Cable/Hose Attachment	Cables and hoses should be attached to minimize interference and drag.			
	Handle Surface	Grip surfaces should be high friction and slip-resistant.			
		Grip surfaces should be compressible.			
	Handle Shape	There should be no hard/sharp edges or abrupt curves that the contact user's hand or body. Avoid ridges or channels for individual fingers.			
	Handle for Torquing Tools	For torquing tools, the handle should be long enough to prevent grip forces above 8 lb. (3.6 kg.)			

Comments:

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Table A.3
Hand Tool/Power Tool Evaluation Worksheet (Cont'd.)

Date:			**Evaluator:**		
Job:			**Type:**		
Manufacturer:			**Model Number:**		
Model Name:			**Price:**		
Category	**Parameter**	**Measure**	**Meets Criteria Yes**	**No**	**N/A**
Force Requirements Cont'd	Trigger Force	Force required to activate the trigger should be insignificant (considerably less than 1 lb. or 0.5 kg.)			
	Trigger Function	Tool should avoid continuous activation of a trigger.			
	Connection Force	Force required to connect/disconnect the power tool should be insignificant.			
	Spring Release (Plier-Type Tools)	Plier-type tools should have a spring release mechanism. The spring tension should be minimal.			
Handle Size	Grip Diameter	Grip Diameter for a full hand grip tool should be between 1-1.5" (2.5-3.8 cm.).			
		Grip Diameter for a fingertip grip tool should be between 0.25-0.5" (0.6-1.3 cm.).			
		It should also be possible to increase the diameter of the handle if needed.			
	Handle Span on Plier-Type Tools	Plier-type tools should have a span of less than 3" (7.6 cm.).			
	Total Grip Length	4" (10.2 cm.) minimum, 5" (12.7 cm.) preferred			
Trigger/ Buttons	Trigger/ Button Location	Triggers and buttons should be positioned to prevent extension of fingers or the thumb.			
	Trigger/ Button Shape	Trigger should have large smooth curves. No hard edges or points (particularly at the end of the trigger).			
	Trigger Length	1.5" (3.8 cm.) minimum, 2-2.5" (5.1-6.4 cm.) preferred			
	Trigger Width	0.5-1.0" (1.3-2.5 cm.).			
	Trigger Ridge Depth	0.125" - 0.375" (0.318-0.953 cm.)			
	Trigger Range of Movement	Trigger should have a small range of movement.			
Comments:					

Atch 1 (2 of 3)

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Table A.3
Hand Tool/Power Tool Evaluation Worksheet (Cont'd.)

Date:			**Evaluator:**		
Job:			**Type:**		
Manufacturer:			**Model Number:**		
Model Name:			**Price:**		
Category	**Parameter**	**Measure**	**Meets Criteria**		**N/A**
			Yes	**No**	
Misc.	Heat Conduction	Tool handle should be coated or rubberized (tool handles should not be bare metal)			
	Routing of Air Exhaust	Air powered tools should not blow cold air on hands.			
	Torque/ Impact	Tool should not expose the user to excessive torque or impact.			
	Vibration	Tool should not expose the user to excessive vibration.			
Comments:					

Level I Ergonomics Methodology Guide for Maintenance and Inspection Work Areas, Appendix 5, January 1997, Pacific Environmental Services, INC.

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Resources for Ergonomic Training Videos

This list does not imply endorsement by DoD or the USAF.

1. Black Mountain Safety & Health- vendor. www.safety-video-bmsh.com

2. National Safety Compliance- vendor. www.osha-safety-training.net

3. The Richardson Company- vendor. www.rctm.com

4. Training ABC.com- vendor. http://trainingabc.com/ergonomics.htm

5. Washington State Department of Labor and Industries- Video lending library. www.lni.wa.gov

Atch 2

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References

1.Bruce, Bernard (Editor). (1997). *Musculoskeletal Disorders and Workplace Factor: A Critical Review of Epidemiologic Evidence for WMDs of the Neck, Upper Extremity and Low Back.* National Institute for Occupational Safety and Health.

2. Cal/OSHA Education and Training Unit. (1999). *Easy Ergonomics: A Practical Approach for Improving the Workplace.* California Department of Industrial Relations.

3. Eastman Kodak Co. (1983). *Ergonomic Design for People at Work* (Vol 1). New York: Van Nostrand Reinhold Co.

4. Karwowski, W., Marras, W. (1999). *The Occupational Ergonomics Handbook.* CRC Press.

5. Pacific Environmental Services, INC. (1997). *Level 1 Ergonomics Methodology Guide for Maintenance and Inspection Work Areas.* USAF.

6. Putz-Anderson, Vern (Editor). (1988). *Cumulative Trauma Disorders: A Manual for Musculoskeletal Diseases of the Upper Limbs.* Taylor & Francis, Ltd.

Atch 3

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